

WHAT IS CLAIMED IS:

- 1 1. An optical circulator having a longitudinal axis comprising:
 - 2 a first beam displacer/combiner that displaces at least one optical beam
 - 3 into two polarized component beams and combines at least two polarized
 - 4 component beams to form an optical beam;
 - 5 a first nonreciprocal rotator, optically coupled to the first beam
 - 6 displacer/combiner distally along the longitudinal axis, for rotating the
 - 7 polarization orientation of the polarized component beams;
 - 8 a first beam angle turner, optically coupled to the first nonreciprocal
 - 9 rotator distally along the longitudinal axis, for turning the polarized
 - 10 component beams through an angle, wherein the path of the polarized beam
 - 11 converges to or diverges from the longitudinal axis of the circulator depending
 - 12 upon the polarization and propagation direction of the polarized component
 - 13 beam;
 - 14 a second beam angle turner, optically coupled to the first beam angle
 - 15 turner distally along the longitudinal axis, for turning the polarized component
 - 16 beams through an angle, wherein the path of the polarized beam converges to
 - 17 or diverges from the longitudinal axis of the circulator depending upon the
 - 18 polarization and propagation direction of the polarized component beam;
 - 19 a second nonreciprocal rotator, optically coupled to the second beam
 - 20 angle turner distally along the longitudinal axis, for rotating the polarization
 - 21 orientation of the polarized component beams; and
 - 22 a second beam displacer/combiner, optically coupled to the second
 - 23 nonreciprocal rotator distally along the longitudinal axis, that displaces at least
 - 24 one optical beam into two polarized component beams and combines at least
 - 25 two polarized component beams to form an optical beam.

- 1 2. The optical circulator according to claim 1, further comprising at least
2 one imaging element, optically coupled to the first beam displacer/combiner
3 proximally along the longitudinal axis, for turning two or more adjacently
4 spaced optical beams in a convergent or divergent propagation direction with
5 respect to the longitudinal axis of the circulator.
- 1 3. The optical circulator according to claim 1, further comprising at least
2 one imaging element, optically coupled to the second beam
3 displacer/combiner distally along the longitudinal axis, for coupling light into
4 or collimating light from the second beam displacer/combiner.
- 1 4. The optical circulator of claim 1, wherein the first and second beam
2 displacer/combiners comprise birefringent crystal plates.
- 1 5. The optical circulator of claim 1, further comprising three or more
2 optical ports distributed such that at least two optical ports are optically
3 coupled to the first beam displacer/combiner proximally along the longitudinal
4 axis, and one optical port is optically coupled to the second beam
5 displacer/combiner distally along the longitudinal axis.
- 1 6. The optical circulator of claim 5, comprising 4 or more optical ports.
- 1 7. The optical circulator of claim 1, wherein the first or second beam
2 angle turners comprise Rochon, Wollaston, or modified Rochon or Wollaston
3 prisms or a pair of birefringent wedges separated by a complete gap.
- 1 8. The optical circulator of claim 7, wherein the each of the first or
2 second beam angle turners comprise two or more Rochon, Wollaston, or
3 modified Rochon or Wollaston prisms or a pair of birefringent wedges
4 separated by a complete gap.

PATENT

1 9. The optical circulator of claim 1, wherein the first and second beam
2 angle turners define a complete gap along the longitudinal axis of the optical
3 circulator and between the first and second beam angle turners.

1 10. The optical circulator of claim 1, wherein the first or second beam
2 angle turner defines a complete gap along the longitudinal axis of the
3 circulator and the complete gap separates portions of the first or second beam
4 angle turners.

1 11. The optical circulator of claim 1, wherein the first or second
2 nonreciprocal rotators comprise Faraday rotators.

1 12. The optical circulator of claim 1, wherein the first or second
2 nonreciprocal rotators comprise two or more nonreciprocal rotators, and each
3 of the two or more nonreciprocal rotators rotates a polarization orientation of
4 polarized component beams passing through to it a same or different
5 polarization orientation with respect to others of the two or more nonreciprocal
6 rotators.

1 13. The optical circulator of claim 12, wherein each of the two or more
2 nonreciprocal rotators rotates a polarization orientation of polarized
3 component beams passing through to a different polarization orientation with
4 respect to others of the two or more nonreciprocal rotators

1 14. The optical circulator of claim 1, where polarization mode dispersion is
2 substantially eliminated.

1 15. An optical circulator having optical beam paths comprising:

2 a first beam displacer/combiner that displaces at least one optical beam
3 into two polarized component beams and combines at least two polarized
4 component beams to form an optical beam;

5 a second beam displacer/combiner, optically coupled to the first beam
6 displacer/combiner optically coupled to the first beam displacer/combiner
7 along the optical beam paths, that displaces at least one optical beam into two
8 polarized component beams and combines at least two polarized component
9 beams to form an optical beam;

10 a first beam angle turner, optically coupled to the first beam
11 displacer/combiner along the optical beam paths, for turning the polarized
12 component beams through an angle, wherein the path of the polarized beam
13 converges to or diverges from the beam path possessed by the polarized
14 component beams immediately before entering the first beam angle turner
15 depending upon the polarization and propagation direction of the polarized
16 component beam;

17 a second beam angle turner, optically coupled to the second beam
18 displacer/combiner and the first beam angle turner along the optical beam
19 paths, for turning the polarized component beams through an angle, wherein
20 the path of the polarized beam converges to or diverges from the beam path
21 possessed by the polarized component beams immediately before entering the
22 second beam angle turner depending upon the polarization and propagation
23 direction of the polarized component beam;

24 a first nonreciprocal rotator, optically coupled to the first beam
25 displacer/combiner and the beam angle turner along the optical beam paths, for
26 rotating the polarization orientation of the polarized component beams; and

27 a second nonreciprocal rotator, optically coupled to the second beam
28 angle turner and the second beam displacer/combiner, for rotating the
29 polarization orientation of the polarized component beams.

1 16. The optical circulator according to claim 15, further comprising at least
2 one imaging element, optically coupled to the first beam displacer/combiner,
3 for turning two or more adjacently spaced optical beams in a convergent or
4 divergent propagation direction from the beam path possessed by the optical
5 beam immediately before it enters the first imaging element.

1 17. The optical circulator according to claim 15, further comprising at least
2 one imaging element, optically coupled to the second beam
3 displacer/combiner, for coupling light into or collimating light from the
4 second beam displacer/combiner.

1 18. The optical circulator of claim 15, wherein the first and second beam
2 displacer/combiners comprise birefringent crystal plates.

1 19. The optical circulator of claim 15, further comprising three or more
2 optical ports distributed such that at least two optical ports are optically
3 coupled to the first beam displacer/combiner, and one optical port is optically
4 coupled to the second beam displacer/combiner.

1 20. The optical circulator of claim 19, comprising 4 or more optical ports.

1 21. The optical circulator of claim 15, wherein the first or second beam
2 angle turners comprise Rochon, Wollaston, or modified Rochon or Wollaston
3 prisms or a pair of birefringent wedges separated by a complete gap.

1 22. The optical circulator of claim 21, wherein the each of the first or
2 second beam angle turners comprise two or more Rochon, Wollaston, or
3 modified Rochon or Wollaston prisms or a pair of birefringent wedges
4 separated by a complete gap.

1 23. The optical circulator of claim 15, wherein the first and second beam
2 angle turners define a complete gap along the optical beam paths.

1 24. The optical circulator of claim 15, wherein the first or second beam
2 angle turner defines a complete gap along the optical beam paths and the
3 complete gap separates portions of the first or second beam angle turners.

1 25. The optical circulator of claim 15, wherein the first or second
2 nonreciprocal rotators comprise Faraday rotators.

1 26. The optical circulator of claim 15, wherein the first or second
2 nonreciprocal rotators comprise two or more nonreciprocal rotators, and each
3 of the two or more nonreciprocal rotators rotates a polarization orientation of
4 polarized component beams passing through to a same or different polarization
5 orientation with respect to others of the two or more nonreciprocal rotators.

1 27. The optical circulator of claim 26, wherein each of the two or more
2 nonreciprocal rotators rotates a polarization orientation of polarized
3 component beams passing through to a different polarization orientation with
4 respect to others of the two or more nonreciprocal rotators

1 28. The optical circulator of claim 15, wherein the polarization mode
2 dispersion is substantially eliminated.

1 29. An optical telecommunications system comprising the optical
2 circulator of claim 1.

1 30. The optical telecommunications system of claim 29, wherein the
2 optical telecommunications system comprises a wavelength division

3 multiplexer, an Erbium-doped fiber amplifier, an add-drop multiplexer, a
4 dispersion compensator, or an optical time domain reflectometer

1 31. An optical telecommunications system comprising the optical
2 circulator of claim 15.

1 32. The optical telecommunications system of claim 31, wherein the
2 optical telecommunications system comprises a wavelength division
3 multiplexer, an Erbium-doped fiber amplifier, an add-drop multiplexer, a
4 dispersion compensator, or an optical time domain reflectometer

1 33. A method of adjusting beam separation of optical beams in the
2 circulator of claim 1 comprising adjusting a length of a complete gap along the
3 horizontal axis of the circulator and defined by the first and second beam angle
4 turners.

1 34. A method of adjusting beam separation of optical beams entering or
2 exiting the circulator of claim 15 comprising adjusting a length of a complete
3 gap defined by the first and second beam angle turners.

1 35. A method of circulating a optical signal comprising passing it though
2 an optical pathway wherein the optical pathway comprises at least one
3 circulator according to claim 1.

1 36. A method of circulating a optical signal comprising passing it though
2 an optical pathway wherein the optical pathway comprises at least one
3 circulator according to claim 15.

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5 37. A method of transmitting an optical beam comprising:

6 passing the optical beam through a nonreciprocal optical device
7 comprising at least one beam angle turner.

1 38. A modified Rochon prism comprising a pair of birefringent wedges
2 optically coupled to one another, and an optical axis of one of the pair of
3 birefringent wedges being oriented normal to the plane of normal incidence,
4 and an optical axis of the other birefringent wedge being oriented 45 degrees
5 in a plane of normal incidence with respect to an optical axis orientation the
6 other birefringent wedge would possess in a conventional Rochon prism.

1 39. A modified Wollaston prism comprising a pair of birefringent wedges
2 optically coupled to one another, and an optical axis of each of the pair of
3 birefringent wedges being oriented perpendicularly to each other and 45
4 degrees in a plane of normal incidence with respect to an optical axis in a
5 conventional Wollaston prism.

1 40. An optical circulator comprising the modified Rochon or Wollaston
2 prism of claim 38.